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00575 | Research Article

Cultivation Conditions and Varietal Features Influence Seed Yield and Quality of Switch Grass (*Panicumv virgatum* L.)

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Abstract

The goal of this study was to investigate the factors affecting the biological dormancy of seeds and to develop methods for reducing it. The study was conducted using the mid-late octaploid variety Cave-in-rock and the mid-season tetraploid variety Sunburst. Seed quality was determined using a method developed by the Institute of Bioenergy Crops and Sugar Beets. Switch grass (*Panicum virgatum* L.) seed yield depends on growing conditions and the location of seed formation on plants. The highest yield was obtained on the first tier of spikes and ranged from 0.47 to 1.67, depending on growing conditions. The highest seed yield was obtained in the Cave-in-rock variety in the conditions of the Western Forest-Steppe and ranged from 1.37 to 1.84 g/plant, depending on the panicle tier. It was determined that seed yield depended on the sum of active temperatures. Thus, with a decrease in the sum of active temperatures to 2910.1 °C, seed yield decreased to 0.41 g/plant. It was found that seed quality - germination energy, germination, and weight of 1,000 switchgrass (*Panicumv virgatum* L.) seeds depended significantly on growing conditions, namely the placement of seeds in the Right-Bank and Left-Bank Forest Steppe of Ukraine and matrical diversity of the place of seed formation on plants. On average, by variety, the weight of 1,000 seeds on the first tier panicles was higher in all soil and climate zones of cultivation and ranged from 1.56 g/plant in the Left Bank Forest-Steppe to 1.77 g/plant in the Right Bank Forest-Steppe. Seed germination in the Western and Left-Bank Forest-Steppe was higher in the Sunburst variety and amounted to 78% and 35%, respectively, while in the Right-Bank Forest-Steppe it was higher in the Cave-in-rock variety – 33%.

Keywords

Panicle; Tier; Germination; Germination energy; Weight of 1000 seeds

Introduction

Technological progress, economic development, and manufacturing now fully meet the needs of society. However, excessive use of resources and damage to the environment are prompting a rethinking of how they are extracted and used (Shlapak *et al.*, 2025). In the modern world, which faces climate challenges, depletion of natural resources, and environmental crises, the green transformation of economies is becoming a priority for many countries around the world (Valiyeva and Garashli, 2025). Progressive increases in crude oil and natural gas prices make perennial grass biomass production competitive with fossil sources (Smeets, Lewandowski and Faaij, 2009). Biomass, organic matter from numerous sources, plants, microorganisms, and animals, offers a vast and diverse raw material for bioenergy production (Saravanan *et al.*, 2025). Perennial plants are mostly herbaceous grasses that can be harvested on average once per year without the need to re-till and replant for several years (Scordia and Cosentino, 2019). Switchgrass displays an excellent potential to serve as a non-food bioenergy feedstock for pellet and bioethanol production (Matin *et al.*, 2023; Zhang Fu *et al.*, 2017). It has a low raw material cost (Sanderson *et al.*, 1994), requires minimal material investments, and ensures high biomass yield even when grown on unproductive land (Vogel *et al.*, 2002). The suitable pH for switchgrass varied from 4.5 to 7.6 (Virgilio, Andrea and Gianpietro, 2007). However, switchgrass has a significant biomass yield variation even in the same field (Kiniry *et al*., 2005). The crop is propagated with seeds and rhizomes, the former being a simpler method (Elbersen *et al*., 2001).

Switchgrass (*Panicum virgatum* L.) is a broadly adapted warm-season grass species (Hartman *et al.*, 2011). Analysis of climate scenarios shows that more and more areas are becoming suitable for growing switchgrass due to the global warming trend (Barney and Di Tomaso, 2010). Switchgrass is a short-day crop (Van Esbroeck, Hussey and Sanderson, 2003). That is why phenology is influenced by day length. The timing and length of phenological events differed as switchgrass (*Panicum virgatum* L.) cultivars were moved southward or northward (Sanderson and Wolf, 1995). Switchgrass has two ecotypes: lowland and upland, categorized by their adaptation to different latitudes and moisture conditions (Moser and Vogel, 1995). The research on the morphological development and relationship of growing degree-days (GDD) to plant morphology and tiller characteristics was made to compare nine cultivars of switchgrass in southwestern Quebec (Madakadze *et al.*, 1998). It was indicated that warm-season grasses can be grown successfully in eastern Canada. The highest quality indicators were typical for an early cultivar (Dacotah), an early-ripening cultivar (Forestburg), and average-ripening cultivars (Nebraska, Sunburst) in the field experiment conducted at the Forest steppe of Ukraine (Dryha *et al.*, 2022). The biggest difference in morphology between the switchgrass genotypes has been observed in the third year of growth (Rakhmetova *et al*., 2020). It has also been shown that some genotypes (Ukrainian cultivar Zoriane) can produce more biomass than the widely known variety Alamo. Meanwhile, a new switchgrass variety, Espresso, was developed from seven cycles of phenotypic recurrent selection for rapid seed germination without a stratification period (Rushing, Baldwin and Morrison, 2024). The germination and emergence of Espresso was significantly greater than seeds from 'Alamo' and 'Kanlow' over 2 years. It was found that lowland switchgrass varieties produce stems that are significantly longer than those of upland varieties; however, the number of stems and leaves is greater in upland varieties

(Rytchenko, Rozhko and Kulyk, 2023). It was found that the highest yield of germinating seeds is provided by the varieties of switchgrass of the upland ecotype: 'Zoriane', 'Morozko' and 'Liadovske', 'Cave-in-Rock', 'Carthage', and 'Forestburg'.

The switchgrass seeds are very resilient to environmental fluctuations, leading to low field emergence and uneven seedlings, consequently reducing crop productivity (Kimura *et al.*, 2015). This is a major limiting factor for the widespread introduction of switch-grass into production (Grabowski *et al.*, 2002). Therefore, the main goal of our case study was to estimate the biological dormancy state of seeds in different parts of the forest-steppe heat of Ukraine. The objective of the study was to determine the characteristics of yield formation and seed quality of switchgrass (*Panicum virgatum* L.) depending on the biological traits of the crop, specifically, the location of seeds on the plants and the influence of weather conditions during the growing season.

Methodology

Study Area

The studies were conducted at the Institute of Bioenergy Crops and Sugar Beets of the National Academy of Agrarian Sciences of Ukraine, as well as at the research and breeding stations of the Institute, throughout the years 2019-2022. Field studies were conducted under various growing conditions: Right-bank Forest-Steppe - experimental field of the Institute of Bioenergy Crops and Sugar Beets - Kyiv region, Bila Tserkva district, village of Ksaverivka 2; Left-bank Forest-Steppe - Velelopodolyan Research and Selection Station, Poltava Region, Semenivsky District, Veselyi Podil village; Western Forest-Steppe - Yaltushkiv Research and Selection Station, Vinnytsia Region, Barsky District. Seeds were collected from the panicles of the first, second, and third tiers, with 15 to 20 plants per tier representing 100% of their browning. The panicles of the first tier were located on the most developed stems, which were the tallest. The panicles of the second tier were on less developed stems that were shorter in height, and those of the third tier were even shorter.

The research was carried out using a mid-late octaploid cultivar sample, Cave-in-rock, and a mid-maturing tetraploid cultivar sample, Sunburst. Weather conditions during the flowering and seed ripening phases were favorable for the formation of seed quality.

Research Methods

Seed quality was determined using a methodology developed by the Institute of Bioenergy Crops and Sugar Beets (Doronin *et al*., 2019). The guidelines of the International Union for the Protection of New Varieties of Plants (UPOV) were also used for visual assessment of plant traits (UPOV, 2007). Seed yield was determined by weighing each plot from each repetition. Germination energy was determined on day 15, and germination rate on day 20. The corresponding indicators were determined at a germination temperature of 20 °C after preliminary cooling of the seeds at a temperature of 10 °C for 7 days.

Soil and Weather Conditions

The studies were carried out under conditions of unstable moisture in the Right Bank part of the Western Forest-Steppe zone and insufficient moisture in the Left Bank part of the Forest-Steppe zone of Ukraine. The average annual air temperature in the Right-Bank Forest-steppe zone is +7 °C, with significant deviations ranging from 5 to 8 °C in some years. The maximum summer temperature reaches 37-39 °C, and the minimum winter temperature is -36 °C. Generally, the vegetation conditions are favorable for the growth and development of the crops. The average annual precipitation amount is 538 mm, ranging from 350 to 850 mm in the Western Forest-steppe zone. The average temperature during the growing season is 13.5 °C, and the average annual precipitation amount is 400 mm. The average annual air temperature in the eastern part of the Left-Bank Forest-steppe zone is +7.7 °C, and the average annual precipitation amount is 511 mm, with 326 mm during the growing season. Overall, the years under the research were typical for these regions' weather conditions, with minor deviations from the long-term indicators.

Data collection techniques

Experimental data were obtained through field studies in the Right-Bank Forest-Steppe at the Institute's experimental field, in the Left-Bank Forest-Steppe at the Veselopodyanska Experimental and Selection Station, and in the Western Forest-Steppe at the Yaltushkivska Experimental and Selection Station of our Institute.

Statistical Analysis

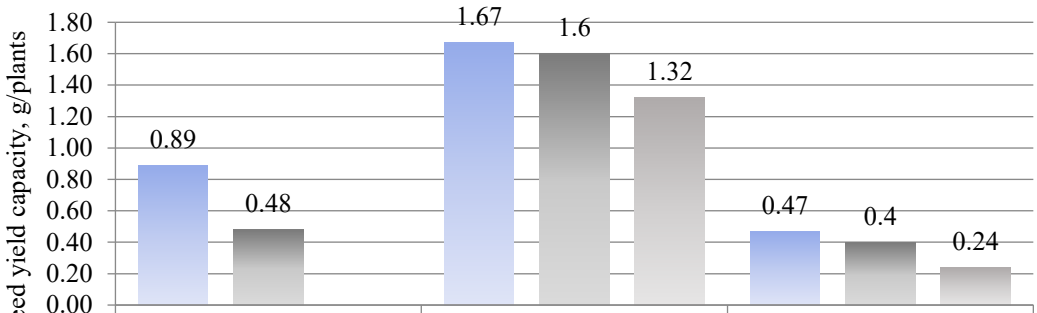
Data received in field experiments accomplished were processed by statistical methods using the software package StatGraphics Plus5, with all tests of significance being made at a type 1 error rate of 5%.

Results and Discussion

Modern agricultural production faces significant challenges, primarily related to extreme weather events caused by global climate change (Hossain, Atibudhi and Mishra, 2023; Opalchuk *et al.*, 2024; Wu *et al.*, 2025). According to forecasts, global warming will be the main factor slowing down plant growth and development across large areas over the next 50 years. Therefore, xerophytic plants adapted to changing complex climatic conditions should become strategic crops (Bolan *et al.*, 2024; Vendramini, Silveira and Moriel, 2023). Due to its high yield potential, adaptability to environmental factors, and low resource requirements, *Panicum virgatum* L. is considered one of the main grass energy crops in many countries around the world (Bouton, 2008; Norkeviciene *et al.*, 2025). Switchgrass requires minimal agricultural inputs and can grow well on marginal lands while providing a wide range of ecosystem services (LaGory *et al.*, 2024). Given the growing demand for bioenergy crops, new varieties of switchgrass are currently being actively developed and tested under various growing conditions (Pecheniuk *et al.*, 2024).

Research by Wasonga *et al.* (2025) has revealed significant differences in the biomass yield of switchgrass depending on the year, variety, and fertilizer application. Biomass yield during 2021–2023 ranged from 6.9 to 9.2 Mg ha^{-1}, with the lowest yield in 2022, which was

characterized by the driest conditions. It was established that the seed yield depends on both the cultivation conditions and the location of the seed formation on the plants. On average, by the cultivars, significantly higher seed yield capacity was obtained on the panicles of the first tier in all soil-climatic zones of the cultivation (Figure 1).



	Right Bank Forest-Steppe	Western Forest-Steppe	Left-Bank Forest-Steppe
I tier	0.89	1.67	0.47
II tier	0.48	1.6	0.4
III tier	0	1.32	0.24

Figure 1: Seed yield capacity about the cultivation conditions and the place of its formation on the plants (average by the cultivars, 2019-2023)
Note: LSD_{05} cultivation conditions, panicle tier = 0.04 g

The seed yield of the panicles of the second tier in the valleys of the Right Bank Forest-Steppe was twice as low as in the valleys of the first tier. This trend was also evident in the changes in the seeds' productivity on the third tier in the Western and Left Bank Forest-Steppe zones. The seed yield capacity from all tiers was significantly lower when grown under the conditions of insufficient moisture in the Left-Bank Forest-steppe zone, which was due to a water deficit, especially during the interphase period of the seed formation and maturation.

Studies by Mosier and others have determined that yield depends on plant genotype. The highest yield was recorded for the Cave-in-rock variety, at 10.3 ± 0.4 mg ha−1 year−1 (Mosier *et al.*, 2024). The seed yield capacity was significantly higher from the panicles of the first tier in the Sunburst cultivar sample taken in the conditions of the Right-Bank Forest-steppe zone. However, it was lower from the panicles of the second tier as compared with the Cave-in-rock cultivar sample (Table 1).

In Western Forest-Steppe conditions, the yield of Cave-in-rock was significantly higher at 1.67 g/plant, while in Left-Bank Forest-Steppe conditions, this indicator was significantly higher for Sunburst, at 0.44 g/plant. Thus, the studies confirm the importance of growing conditions and genotype on crop yield. Research has shown that the quality of millet seeds is influenced by a number of factors, including storage conditions and duration, varietal characteristics, growing conditions, etc. (Dryha *et al*., 2024). A study of the characteristics of growing switchgrass in the Eastern Forest-Steppe zone of Ukraine has established that growing conditions account for 47% of its productivity, biological characteristics of the variety account for 1%, and the interaction of these factors accounts for 38% (Liubych and Mandrovska, 2024).

Table 1: Seed yield capacity about the cultivation conditions, varietal features, and the place of seed formation on the plants (in 2019-2023)

Variety/ panicle tier		*Seed yield capacity, g/plant*		
Cultivar	*Number*	*Right-Bank Forest-steppe zone*	*Western Forest-Steppe zone*	*Left-Bank Forest-steppe zone*
Cave-in-rock	I	0.87	1.84	0.36
	II	0.52	1.81	0.30
	III	-	1.37	0.23
Sunburst	I	0.91	1.51	0.57
	II	0.44	1.38	0.50
	III	-	1.28	0.25
$LSD_{05\ gen}$		0.09		
$LSD_{05\ cultivation\ conditions,\ cultivar,\ panicle\ tier}$		0.04		

A study of the productivity of switchgrass under different growing conditions has determined that growing conditions account for 89% of the impact (Figure 2), indicating that weather conditions are more stable from year to year and, accordingly, have less impact on crop productivity than conditions in different soil and climate regions.

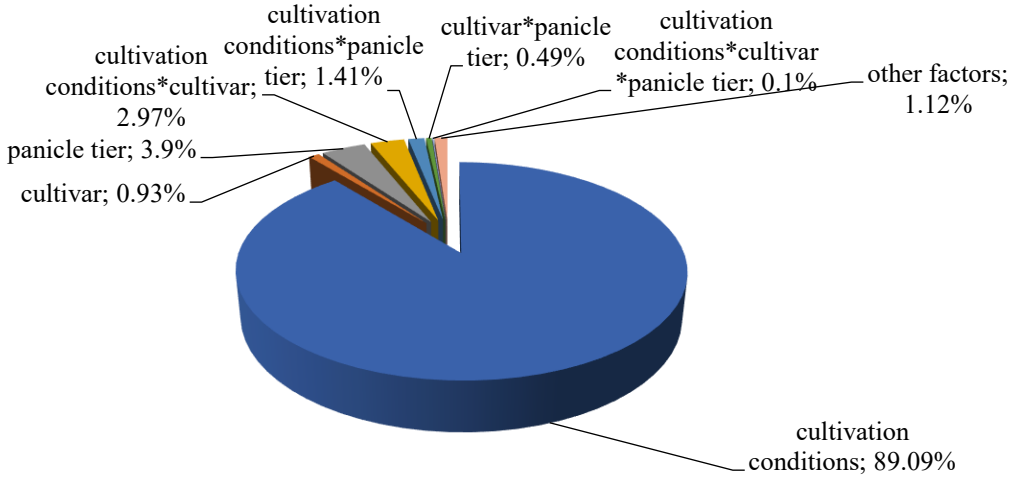


Figure 2: Share of the factor effect on the seed yield capacity

It was established that the sum of active temperatures over 10 °C in the vegetative period had a significantly high effect on the formation of the seed yield capacity (Figure 3).

The highest yield, 1.02 g/plant, was obtained in 2019, when the sum of active temperatures was 3629.6 °C. Seed yield significantly decreased with a decrease in the sum of active temperatures to 2910.1 °C. The correlation coefficient between seed yield and the sum of active temperatures is 0.83. It was found that seed quality - germination energy, germination, and weight of 1000 seeds of switchgrass (*Panicumv virgatum* L.)

significantly depended on growing conditions and matric diversity - the place of seed formation on plants (Table 2).

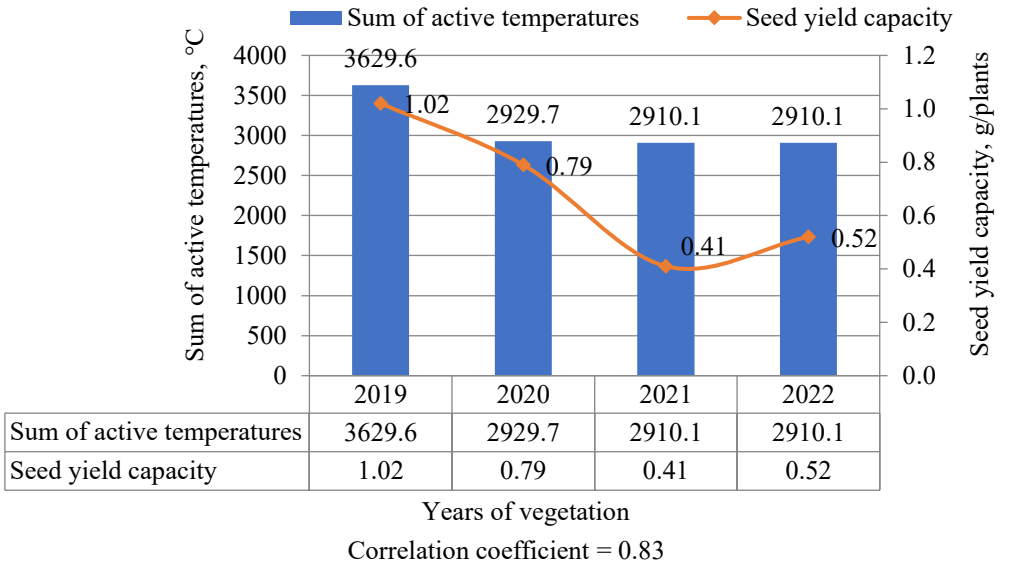


Figure 3: Dependence of the seed yield capacity on the sum of effective temperatures (Right-Bank Forest-steppe zone)

Table 2: Seed indexes about the cultivation conditions and the place of its formation on the plants (average by cultivars in 2019-2023)

Cultivation conditions	*Panicle tier*	*Seed quality, %*		
		Mass of 1000 pcs. g	*germination energy, %*	*emergence, %*
Right-Bank Forest-steppe zone	I	1.77	29	29
	II	1.90	39	39
Western Forest-Steppe zone	I	1.70	58	62
	II	1.75	62	64
	III	1.79	60	64
Left-Bank Forest-steppe zone	I	1.56	31	31
	II	1.33	28	28
	III	1.28	22	22
$LSD_{05\ gen}$			4.8	4.5
$LSD_{05\ cultivation\ conditions}$			3.4	3.2
$LSD_{05\ panicle\ tier}$			2.7	2.6

Reliably higher germination energy and seed emergence, as well as the seed yield capacity, were reached when grown in the conditions of the Western Forest-steppe zone. These indicators were the lowest in the conditions of the Left-Bank Forest-steppe zone, regardless of the panicle location on the plants. It was established that the influence of the 'growing conditions' factor on germination energy and seed germination was the greatest, 91.96 % (Figure 4).

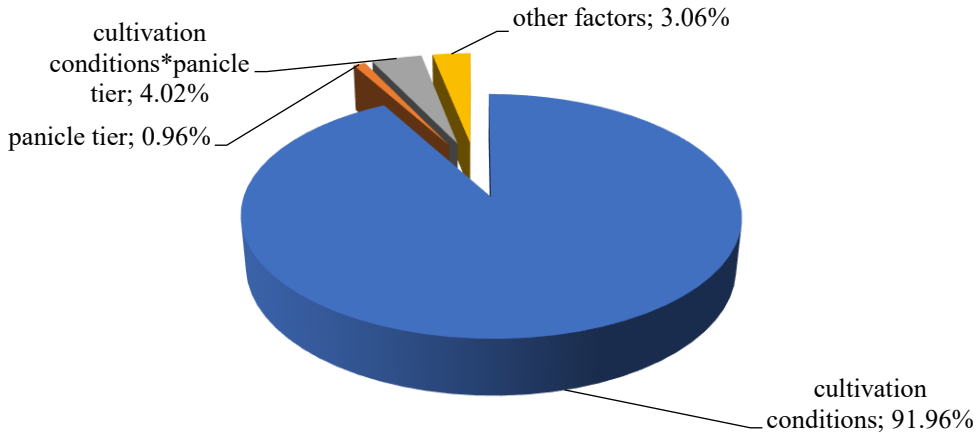


Figure 4: Influence of factors on the seed germination energy (average for 2019-2022)

The study of seed germination depending on the set of traits (genotype, seed formation location on the plant, and growing conditions) showed that seed germination and yield depended on these traits (Table 3).

Table 3: Seed emergence about the cultivation conditions, varietal features, and the place of seed formation on the plants (in 2019-2023)

Variety/ panicle tier		*Seed emergence, %*		
Cultivar	*Number*	*Right-Bank Forest-steppe zone*	*Western Forest-Steppe zone*	*Left-Bank Forest-steppe zone*
Cave-in-rock	I	34	73	25
	II	32	78	21
	III	-	73	13
Sunburst	I	26	76	38
	II	35	80	35
	III	-	79	31
$LSD_{05\ gen}$		2.2		
$LSD_{05\ cultivation\ conditions,\ cultivar,\ panicle\ tier}$		1.8		

Significantly higher seed emergence was obtained from panicles of the first tier of the Cave-in-rock variety sample under the conditions of cultivation of the Right Bank Forest Steppe. Meanwhile, this indicator was significantly higher in the seeds of the Sunburst sample taken from the second tier. Seed emergence of seeds from all tiers of the Sunburst variety sample was higher than Cave-in-rock for seed cultivation in the conditions of Western Forest Steppe and Left Bank Forest Steppe. Research by Rytchenko and Kulyk

(2024) found that the yield of viable switchgrass seeds in Ukraine's central forest-steppe zone is influenced by annual conditions, genotype, and fertilization. In particular, the percentage of viable seeds varied between 47.9% and 52.4%, depending on the conditions of the year. As a result of our research conducted in the conditions of the Left Bank forest-steppe of Ukraine, it was determined that the germination rate of millet seeds ranged from 25 to 35%, depending on the variety. These results necessitate further research on the influence of various factors, including fertilization, on crop quality indicators under different growing conditions.

Conclusion

The seed yield and its quality depended on growing conditions, varietal characteristics, and the place of its formation on the plants. On average, by varieties, higher yields were obtained on panicles of the first tier in all soil and climatic zones of cultivation. In particular, the yield on the first-tier panicles in the conditions of the Right-Bank Forest-Steppe was 0.41 g/plant or 46% higher than on the second-tier panicles. On the third-tier panicles in the Left-Bank Forest-Steppe, the yield was 49% lower, and in the Western Forest-Steppe, it was 21% lower compared to the yield on the first-tier panicles in the corresponding growing conditions. The seed yield from all tiers was significantly lower when grown in conditions of insufficient moisture in the Left-Bank Forest-Steppe and did not exceed 0.47 g/plant. When grown in the conditions of the Western Forest-Steppe and Left-Bank Forest-Steppe, the seeds from all tiers of the Sunburst variety had a significantly higher yield compared to Cave-in-rock and ranged from 1.37-1.84 and 0.23-0.36 g/plant, depending on the growing conditions. Significantly higher germination energy and seed germination were obtained when grown in the Western Forest-Steppe, and the lowest values were obtained in the Left-Bank Forest-Steppe, regardless of the location of the panicle on the plants.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*	*Author 5*	*Author 6*	*Author 7*	*Author 8*	*Author 9*	*Author 10*
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
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Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Wrote the article/paper	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes
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